Symposium 1 Part 2: The Food Chain

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Soils for Sustaining Global Food Production

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ABSTRACT: Soil is commonly described as the mantle or the skin covering the landmass of planet Earth. Soils perform 6 main functions (biomass production, water quality maintenance, biological habitat, physical infrastructure support, raw materials for human use, and maintaining cultural heritage) and a soil is evaluated by its ability to perform one or more of these functions. The ability of the land to feed and clothe people and to maintain ecological functions is being impeded by demographics. The global land area that is generally free of constraints for most agricultural uses is about 12.6%. Agricultural land, however, is unequally spread around the globe with a larger portion in the temperate countries of the world. In addition to poorer land quality in tropical regions, land degradation is also well entrenched, thus aggravating food security. There are 11.9 million km^2 of such lands and about 1.4 billion people are involved and most of these areas are in the developing countries. Countries of the developing parts of the world have to make a conscious decision to better manage their land resources. The paradigm shift that poorer countries need to make to sustain food production is to implement holistic and sustainable land management programs by adopting technologies that have already been validated in other parts of the world.

Introduction

The social, economic, and environmental well-being of humans is strongly linked to soil quality. Sustainable development as a goal for all nations depends on the interdependence of these factors and how human society manages natural resources in a harmonious manner. Soil resources have always been important from the time humans ventured into sedentary agriculture. However, during each stage of the development of societies, the issues, concerns, and societal commitment to manage the resource varied. As populations increased with a concomitant increase in the demand for food and fiber, greater effort was made to understand and enhance the performance of soil resources. Modern soil science is only about 100 years old, but in partnership with other disciplines, it has made major contributions to global food security. In the United States, Europe, and other advanced countries, yields of crops have more than tripled in the last 50 years; even in many developing countries the Green Revolution has brought tangible changes. This progress significantly reduced the probability of global hunger and famine. Today, the total food production is adequate to feed the world. Inadequate or inefficient distribution of the food, however, prevents many from reaping this abundance and leading to an estimated more than 800 million malnourished people. While significant advances are being made to enhance the productivity of soil resources, in some countries of the world the ability to sustain this productivity level is being reduced by overexploitation or inappropriate use of the soil resources.

The issue facing national policy makers in most countries of the world is the ability of the land to produce the food and fiber for the growing populations (Virmani and others 1994). The issue stems from 4 fundamental concerns: The first is land degradation, which results in the decline of the quality and quantity of land. The second is population growth that constantly threatens the ability of the country to feed and clothe the population. The third is unequal access to resources wherein the affluent have disproportionately more land forcing the poor to exploit fragile ecosystems and thereby accelerating land degradation. Finally, the fourth is resource consumption whereby land is permanently taken out of agriculture for urban and other permanent structures. These concerns challenge food security, which is defined as "access by all people at all times to sufficient food for an active and healthy life." The net consequence is that environmental degradation, accentuated by human mismanagement of land, is negatively impacting the basic life support system of planet Earth and some view this as leading to national, regional, and even international conflicts.

The United Nations Conference on Environment and Development at Rio de Janeiro in 1992 has spawned a number of global conventions to protect and conserve the Earth's resources and environment. The shared commitment to enhance the quality of human life while maintaining a balance with the other components of the environment is the goal of all nations. However, the absence of tangible commitments by many nations due to the inability to provide the required investments has yet to result in any meaningful impact. In many developing countries, national policies are either absent or, even in some cases, inadvertently aggravate the

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problems. The global dialogue has, however, resulted in creating the necessary awareness among nations and international collaboration is being initiated to share the responsibilities.

At a conference on sustainable agriculture held in Italy (Bellagio 1999), the participants posed several questions and concluded that there are numerous alternatives to mainstream agricultural research and development and that their application may determine whether the people of this world can successfully meet their needs. There are many obstacles to this optimistic view, the most important of which is the socioeconomic and political state of developing countries where such advances must also take place and where major obstacles exist as illustrated by Cleaver and Schreiber (1994). This is beyond the scope of the present paper, which will only consider the biophysical aspects and specifically the quality of the land and the forces that detract from enhancing productivity. The issue of food security is further complicated in developing countries when it has been achieved at the expense of the integrity of the environment (Durning 1989).

Eswaran and others (1999) showed that of the 130.8 million km^2 of ice-free land about 14.5 million km^2 or 11.1% is arable and used for agriculture and/or grazing. An additional 2.4 million km^2 of land, largely in the arid parts of the world, is irrigated. This 16.9 million km^2 of land currently feeds 6.4 billion people, which is expected to increase to more than 10 billion in the next 25 years. Over the past 40 years, per capita world food production has grown by 25%. Yet the world still faces a fundamental food security challenge, with some 800 million people hungry. What is going to be important is who produces the food, has access to the technology and knowledge to produce it, and has the purchasing power to acquire it. Many countries have reached or are reaching the limits of their land resources. Land degradation and other land consumption processes such as urbanization and infrastructure development are continuously reducing the amount of land for food and fiber production.

In this report on global land resources, we first evaluate the availability of land and the condition of the resource base in the context of the functions that have to be performed. In many countries of the world, there appears to be a systematic decline of the quality of the land, which impacts the abilities of the country to be sustainable. In our assessment of the ability of soils to sustain global food production, answers to some of the following questions are provided:

1. What is the capacity of global soil resources to produce food;

2. As not every soil has the same capacity, where are the best areas and the hotspots;

3. How can the comparative advantages be exploited in a national, regional, and a global manner;

4. What are the needs to feed 10 billion people?

Global soil resources: Their quality and distribution

An assessment of global land resources was made by the U.S. Dept. of Agriculture (Eswaran 1989) and more recent and updated data are presented in Table 1. The global soil map is reproduced in Soil Taxonomy (Soil Survey Staff 1999). In Table 1, the land area occupied by each Soil Order is given and in addition an estimate of the number of people living on such soils is also presented. This is obtained by overlaying a population density map developed by Tobler and others (1995) on the soil map. Ultisols, Alfisols, Inceptisols, and Entisols have the high populations and together support over 70% of the world population. This group of soil occupy about 44% of the land area but members in this group also present favorable conditions for agriculture. In addition, historically communities first established on the alluvial plains and undulating lands that required low traction for management. With technological advances, this changed as evidenced by the increasing use of Vertisols and Aridisols. In the temperate parts of the world, Alfisols and Mollisols have high concentrations of people. The Mollisols occupy about 6.9% of the land surface and have about 6.7% of the population on it. They are some of the best soils of the world but are mostly confined to the temperate countries. In the tropics, much of the population is associated with river terraces (Entisols and Inceptisols) and on Ultisols. The Ultisols and Oxisols are problematic soils for low-input agriculture, but, as demonstrated by the Brazilians, can be made productive with appropriate technology (Buol and Eswaran 1994).

Table 1—Global soil and land quality classes.

Soil and land quality classes	Land		2002 Population	
	Area	%	Area	%
1. Total ice-free land	130.8	100	6400	99.9
2. Kinds of soils:				
Gelisols	11.26	8.61	25	0.4
Histosols	1.53	1.17	31	0.5
Spodosols	3.35	2.56	107	1.7
Andisols	0.912	0.70	110	1.7
Oxisols	9.81	7.50	252	3.9
Vertisols	3.16	2.42	356	5.6
Aridisols	15.7	12.00	353	5.5
Ultisols	11.05	8.45	1148	17.9
Mollisols	9.01	6.89	428	6.7
Alfisols	12.62	9.65	1097	17.1
Inceptisols	12.86	9.83	1266	19.8
Entisols	21.14	16.16	1027	16.0
Shifting sand	5.32	4.07	82	1.3
Rocky land	13.08	10.00	176	2.7
Glaciers, Water bodies	10.01	7.65	6	0.1

The Gelisols of the Boreal zone have the lowest population density with about 2 persons per km^2 while the Andisols (developed on volcanic pyroclastic materials) have the highest with more than 106 persons per km^2. Rwanda, Burundi, and Ituri province of eastern Zaire have the highest population densities in the world and this is followed by the volcanic areas of Southeast and East Asia. The Ultisols and Vertisols that dominate in the tropics have a population density of about 90 and 98 persons, respectively, while the Mollisols and Alfisols, the major grain-producing regions of the temperate regions, have a density of 90 and 41 persons per km^2, respectively. Fragile systems such as those with Histosols and Aridisols have 18 and 20 persons per km^2, respectively, and though these are low, they are already threatening the sustainability of these systems. The largest extent of the Histosols (organic soils) is in Canada. In the tropics, it is in Indonesia where shifting cultivation and very-low-input agriculture is destroying the ecosystem. The recent forest fires in Indonesia are partly due to this mismanagement. Historical land use studies have shown that populations have always sought the better soils for agriculture and, hence, the development of their communities. In more recent times, with advances in technology, particularly irrigation techniques, agriculture has moved into more fragile ecosystems. In the developing countries of the world, a burgeoning population has forced the poor landless also to move into fragile ecosystems or degrade the better resources of their countries.

Land quality is a measure of the land to perform specific functions (Beinroth and others 2001) and the features of each class are given in Table 2. Land quality is assessed by 6 major functions

Table 2—Properties of land quality classes

Land Quality Class	Properties
I	This is prime land. Soils are highly productive, with few management-related constraints. Soil temperature and moisture conditions are ideal for annual crops. Soil management consists largely of sensible conservation practices to minimize erosion, appropriate fertilization, and use of best available plant materials. Risk for sustainable grain crop production is generally <20%.
II & III	The soils are good and have few problems for sustainable production. However, and particularly for Class II soils, care must be taken to reduce degradation. The lower resilience characteristics of Class II soils make them more risky, particular for low-input grain crop production. However, their productivity is generally very high and, consequently, response to management is high. Conservation tillage is essential, buffer strips are generally required and fertilizer use must be carefully managed. Due to the relatively good terrain conditions, the land is suitable for national parks and biodiversity zones. Risk for sustainable grain crop production is generally 20-40% but risks can be reduced with good conservation practices.
IV, V, & VI	If there is a choice, these soils must not be used for grain crop production, particularly soils belonging to Class IV. All 3 Classes require important inputs of conservation management. In fact, no grain crop production must be contemplated in the absence of a good conservation plan. Lack of plant nutrients is a major constraint and so a good fertilizer use plan must be adopted. Soil degradation must be continuously monitored. Productivity is not high and so low-input farmers must receive considerable support to manage these soils or be discouraged from using them. Land can be set aside for national parks or as biodiversity zones. In the semi-arid areas, they can be managed for range. Risk for sustainable grain crop production is 40-60%.
VII	These soils may only be used for grain crop production if there is a real pressure on land. They are definitely not suitable for low-input grain crop production; their low resilience makes them easily prone to degradation. They should be retained under natural forests or range and some localized areas can be used for recreational purposes. As in Class V & VI, biodiversity management is crucial in these areas. Risk for sustainable grain crop production is 60-80%.
VIII & IX	These are soils belonging to very fragile ecosystems or are very uneconomical to use for grain crop production. They should be retained under their natural state. Some areas may be used for recreational purposes but under very controlled conditions. In Class VIII, which is largely confined to the Tundra and Boreal areas, timber harvesting must be done very carefully with considerable attention to ecosystem damage. Class IX is mainly the deserts where biomass production is very low. Risk for sustainable grain crop production is >80%.

(Blum 1998, 2002) each of which are equally important for human well-being:

1. production of biomass through agriculture and forestry;

2. protect the ground water and the food chain against pollution and maintaining biodiversity by filtering, buffering, and transformation activities;

3. contribute to the preservation of the gene reserve by enabling the habitat for biota;

4. provide the physical basis for infrastructural development, such as housing, industrial production, transport, dumping of refuse, sports, recreation, and others;

5. serve as a source of raw materials, furnishing gravel, sand, clay, and other materials;

6. preserve the geogenic and cultural heritage by concealing and protecting archaeological and paleontological materials.

All the functions are important for human well-being, but in the context of this study, the function that is most relevant is to sustain grain production and respond to cultural practices conducive to sustainable land management. Land quality is then assessed as the ability of soils to produce grain and the 9 classes defined by Beinroth and others (2001). The global distribution of the nine LQ classes is depicted in the map of Figure 1 and their respective areas are presented in Table 1 through 3. Class I lands have ideal soils occurring in ideal climates for crop production and are characterized by high productivity, high response to management, and minimal limitations. They occupy only about 2.4 percent of the world's land surface but contribute more than 40 percent of global food and feed output. Over 90 percent of Class I soils are used for grain production, although in some countries (such as in Uruguay) they are used for grazing, perhaps because of the high labor costs associated with cultivation. Due to their productivity, most conservation investments are also found on this class of soils because of the assured rewards to sustainable land management.

The 9.5 percent of the global land resources in LQ Classes II and III have minor limitations that generally are easily corrected and that do not pose permanent restrictions to the use of the land. Most of these lands are in the temperate regions of the world where the climate is moderate, with minimal extremes of rainfall or temperature. These soils respond well to management and the positive effects of appropriate management persist for long periods. Unlike Class I soils that are dominantly in the tropics, Class II and III soils have a wider distribution.

Land quality Classes IV, V, and VI together cover 34 percent of the world's land area, largely in the tropics and support about 54% of the population (Table 3a). These soils have a range of constraints, from high ambient temperatures that reduce germination rates to low nutrient availability that limits biomass production of annual crops (however, some of these lands are niches for specific land use such as plantations of rubber, oil palm, and cocoa in the tropics.) Due to their extent in the tropics (Table 3b) where much of the world's population resides, these lands are of particular significance and require additional research and development initiatives. High population densities, coupled with the prevalence of low-input agriculture, make these lands highly vulnerable to human-induced degradation and desertification.

Land quality Class VII soils occupy about 9 percent of global land area and comprise shallow soils, those with high salt concentrations and those with high organic matter. The first are generally excluded in most assessments of suitable land for agriculture. The peat lands are included in this group due to their fragility and hence the inherent dangers associated with their use. The peat lands may be permanently lost via drainage, as has happened in many parts of Southeast Asia. Their uniqueness stems from the fact that they perform specific roles as wetlands and they are also the most efficient sequesters of organic carbon. These lands support about 11.5% of the population and this amount is constantly increasing in the developing parts of the world due to incursions by the landless.

Land quality Class VIII lands, covering 17 percent of the world's land surface, have low temperatures and/or occur on steep slopes, implying that they are generally unsuitable for agriculture, even though their net primary productivity (NPP) may be moderately high. Included in this class are the extremely fragile peat lands of the high latitudes. Perturbation of this ecosystem through land clearing or climate change results in destruction of the permafrost with accompanying oxidation of the peat. Land quality Class IX occupies about 29 percent of the world's land surface. This group, comprising soils with inadequate moisture to support most annual crops (and also rocky land and sand dunes), has a very low net primary productivity (NPP). Nevertheless, this class includes deep soils that, given high solar radiation in summer, are highly productive under irrigation. Efficient use of water is crucial to the management of such soils as their resilience, for example when degraded by salinization, is generally very low. Classes VII, VIII, and IX lands, because of their fragility and very high risks both for ecosystem integrity and sustainable agriculture, should be free of human intervention. Large areas of the Taiga and tropical peat forests are currently threatened by shifting cultivation, but their highest value may be in the provision of environmental services, such as biodiversity, carbon sequestration, and water quality enhancement.

Table 3a—Land area (million km²) in land quality class with estimate of population (million) in each class.

Land Quality Class	Area	%	Nr people	%
I	3.11	2.38	388	6.1
II	6.51	4.98	908	14.2
III	5.95	4.55	306	4.8
IV	5.17	3.95	753	11.8
V	21.60	16.51	1900	29.7
VI	17.42	13.32	777	12.1
VII	11.79	9.01	735	11.5
VIII	21.83	16.69	119	1.9
IX	35.19	28.59	719	11.2

Sustaining food production

During the next 2 decades, trends in population, income, and urbanization are projected to raise world demand for cereals and tubers by 40%, and for meat by about 60% (Pinstrup–Andersen and others 1999). The ability to become sustainable varies, depending on the natural resources available and their conditions in each country. As the increased production to meet this demand will have to come from increased productivity, at least in Asia, the state of the resource base determines the ability of each country to meet its food and fiber needs.

There are a number of estimates on global population supporting capacity and Eswaran and others (1999) employed the concept of land quality and relative grain producing capacity to make such estimates. The assessment is used here only to show magnitudes and geographic areas of concern. By merely using Class I land it is possible to support the current world population in an idealistic society, where everything is shared and there is no problem for access to food. The same ideal global society can support more than 30 billion persons if it uses all the land from Class I through V. This is the absolute maximum. In a more pragmatic world, Class I and II lands together can support about 10 billion people. The conclusion of this study, similar to the assessment by Greenland and others

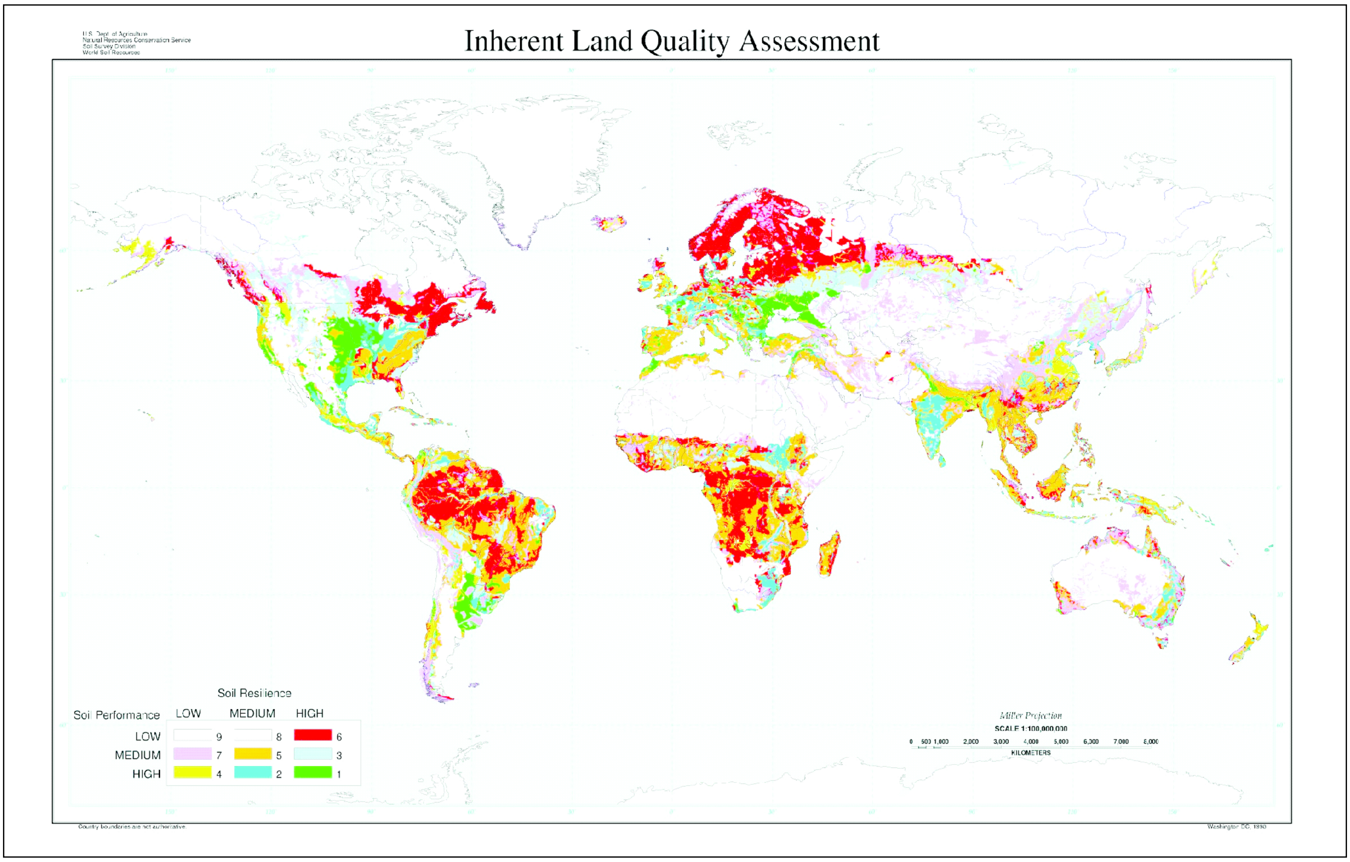

Figure 1—Global map of land quality.

Table 3b—Percent of land area in major biomes as a function of land quality.

	Land Quality Class (Percent of ice-free land surface)									
Biomes	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**Total**
Tundra								15.62		15.62
Boreal			2.03	0.67	0.50	3.05	2.63	1.08	0.07	10.02
Temperate	2.14	2.55	0.70	1.31	4.76	1.66	2.01		0.15	15.29
Mediterranean			0.30	0.15	1.35	0.08	0.65		0.03	2.56
Desert							1.42		28.19	29.61
Tropical	0.25	2.43	1.51	1.83	9.90	8.53	2.31		0.16	26.90
Total	2.38	4.98	4.55	3.95	16.51	13.32	9.01	16.69	28.59	100.00

(1998), is that famine and starvation of people of some countries is not because of the inability of global land resources to produce the necessary food. Class I and II lands do not occur in all countries. Some countries, such as Afghanistan and Pakistan, have an insignificant amount of Class I through IV lands, and hence have to rely on risky irrigation of Class VII lands to meet their food needs. Kuwait and Japan, with similar land resource problems, rely on other pathways to provide the food. A more rigorous analysis was made by Beinroth and others (2001) for Asia and they showed that, for Asia as a whole, food insecurity is an acute problem. In fact, for some countries the Malthusian prophecy is rapidly becoming a reality. The study also revealed the relative scarcity of prime agricultural land in Asia and the resulting imperative to preserve these areas for food production and optimize the land use of the remaining areas.

It is evident that not all countries are endowed with good-quality land resources to produce all the food they need. The situation is aggravated by the fact that in countries characterized by a predominance of limited resource farmers, who are caught in the poverty spiral (Figure 2) described by McCowan and Jones (1992), land degradation and desertification are further reducing the capacity of soils to produce.

Although soils play an important role in sustaining food production, the challenge is to enable this in the socioeconomic and political context. It must be recognized that each country has a range of soils that vary in productivity and fragility. Optimizing land use in countries with a dominance of agrarian population is difficult. An important policy challenge for both industrialized and developing countries is to find ways to maintain and enhance food production, while seeking both to improve the positive functions and to eliminate the negative ones, so improving the overall sustainability of rural livelihoods and economies. Figure 3 illustrates how one country—the United States—addressed the issue. The figure shows changes since 1948 and all the variables are compared with the status in 1948. From 1948, the total land area under cultivation shows a gradual decline. The inputs for production have declined, but with an increase in the outputs. Productivity (a ratio of outputs to inputs) shows a systematic increase with time. The efficiency of production (productivity per unit land) is more revealing. It shows a linear increase until about 1982 when grain crops had a high price. With the high price, less-suitable land was brought under production with a concomitant decline in efficiency of production. However, about 1982, the Conservation Reserve Program, whereby farmers were rewarded for setting aside unproductive land, came into effect. Since then efficiency of production has increased almost geometrically. This is an illustration of the impact of enabling conservation policies. Similar examples are also available in Europe, but such policies do not exist in many developing countries as a consequence of which land degradation is rampant.

Conclusion

The ability of the land to feed and clothe people and to maintain ecological functions is being impeded by demographics. In addition to these population-linked issues are others, which are hu-

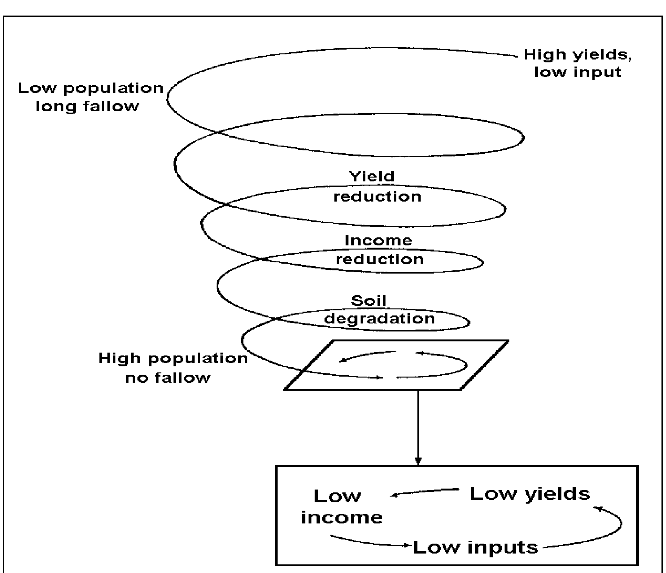

Figure 2—The poverty spiral dilemma of limited resource farmers.

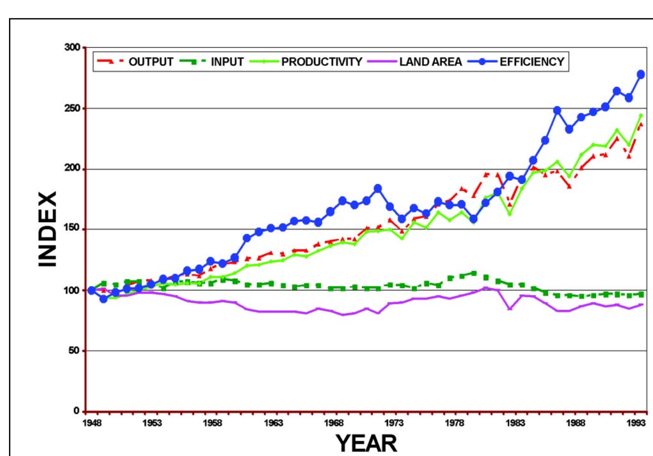

Figure 3—Productivity and efficiency of land use.

man-induced and represent a new generation of global environmental problems. The global land area that is generally free of constraints for most agricultural uses is unequally spread around the globe with a larger portion in the temperate countries of the world. In addition to poorer land quality in tropical regions, land degradation is also well entrenched, aggravating food security. There are 11.9 million km^2 of such lands and about 1.4 billion people are involved and most of these areas are in the developing countries.

Food security then becomes a major issue in those countries that are not blessed with good land resources or those who have degraded or are degrading their resources. Countries of the developing parts of the world have to make a conscious decision to better manage their land resources. The paradigm shift that poorer countries need to make to sustain food production is to implement holistic and sustainable land management programs by adopting technologies that have already been validated in other parts of the world. To assure sustained use of soil resources:

- Research investments must contribute to new knowledge and more productive means of food production;
- An active program of assessment and monitoring of land degradation must be instituted to provide accurate and unbiased information;
- A proactive commitment to sustainability must be made, partly through wise land-use planning and implementation, to ensure that biodiversity is maintained and environments are preserved and protected;
- Appropriate national and international policy environments must exist to enable access to food through a fair and equitable market system so that countries can capitalize on niches;
- It must be recognized that the human carrying capacity of the land is not merely a national problem, but a global one, since it impacts every aspect of human society and is strongly linked to the soil resources.

Finally, the environmental and human health effects of mismanagement of land are wide-ranging and include: (i) sealing of land, (ii) chemical pollution contaminating water and harming wildlife and human health; (iii) excessive use of fertilizers such as nitrate and phosphate fertilizers, livestock wastes, and silage effluents contaminating water, and thereby contributing to algal blooms, deoxygenation, fish deaths, and hazards for recreation; (iv) soil erosion disrupting water courses, and runoff from eroded land causing flooding and damage to housing and natural resources and resulting in billions of dollars of damage; (v) harm to the food-chain exposed to toxic residues and microorganisms in foods; and (vi) contamination of the atmospheric environment by methane, nitrous oxide, and ammonia derived from livestock, their manure, and fertilizers. The social cost of these is high, but more important is the loss of natural capital that cannot be replenished.

Properly managed, land also delivers valued nonfood functions, many of which cannot be produced by other economic sectors. The aesthetic value, recreation and amenity, water accumulation and supply, nutrient recycling and fixation including carbon sequestration, wildlife, including agriculturally beneficial organisms, and storm protection and flood control are examples. Positive social externalities include provision of jobs, contribution to the local economy, and to the social fabric of rural communities.

To sum up, soils are crucial to sustain food production; and to enable soils to perform their functions efforts must be made to protect and conserve the soil resource.

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